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EFFECT OF INITIAL TEMPERATURE ON COMBUSTION OF AMMONIUM PERCHLORATE

by

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8

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EFFECT OF INITIAL TEMPERATURE ON COMBUSTION OF AMMONIUM PERCHLORATE

A. P. Glazkova and V. K. Bobolev

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During the combustion of ammonium perchlorate certain anomalies are observed, the causes of which are as yet unclear. Friedman et al. [1], beginning in the 1950's a study of the combustion of ammonium perchlorate, established upper and lower limits of combustion with respect to pressure. The most recent investigations have shown [2] that the presence of an upper limit is connected with thermal losses and is not observed when the diameter of specimens is greater than that used in work [1]; however, at pressures above 150 at. the rate of combustion is reduced with an increase in pressure, where burning proceeds unstably and with pulsations. A study of temperature distribution during ammonium perchlorate combustion [3], conducted by means of the method of precise thermocouples developed by Zenin [4], led to the establishment of still another anomaly: the temperature of the surface of burning ammonium perchlorate and the liberation of heat in the condensed phase both drop with a growth in pressure, even in the region of stable burning.

In connection with this it is of interest to study the effect of initial temperature on the rate and character of ammonium perchlorate combustion and to consider whether or not an increase in initial temperature will lead to elimination of the upper limi

with respect to pressure and to an increase in stability of combustion.

The information which is available in the literature with respect to the effect of initial temperature on ammonium perchlorate combustion relates to the region of low (up to 150 at.) pressures [5], where combustion is stable.

In this work we studied the effect of initial temperature on ammonium perchlorate combustion in the temperature region from 20 to 150°C and at pressures from the lower limit up to 350 at. We used unarmored specimens of unsifted ammonium perchlorate, 7 mm in diameter and 25-30 mm high, which were compacted to a density of 1.93-1.94 g/cm^3. The rate of combustion was determined photographically [6]. The experiments at elevated temperatures were conducted according to the procedure described by Andreyev and coworkers [7].

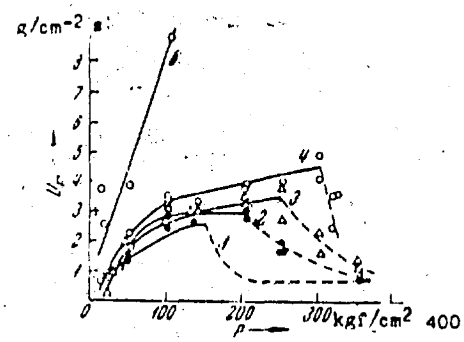

Fig. 1.

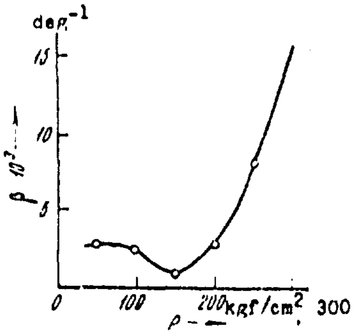

Fig. 2.

Fig. 1. Effect of initial temperature on the pressure dependence of the burning rate of ammonium perchlorate. 1 – 20° [2], 2 – 50°, 3 – 100°, 4 – 150°, 5 – 175°. The broken lines designate the region of pulsation burning.

Fig. 2. Dependence of the temperature coefficient of burning rate on pressure in the interval 50-150°.

As the experiments showed, an increase in the initial temperature leads to an increase in the burning rate and to a reduction of the lower limit with respect to pressure. The higher

the temperature, the lower will be the pressure at which the specimens used in this work begin to burn. Thus, at room temperature the lower limit comprised 30 at. [2]; an increase of initial temperature to $100^{\circ}C$ led to a reduction of the lower limit to 23 at., while at 150° it was reduced to 15 at. (Fig. 1).

Besides the reduction of the lower limit which has been noted, an increase in the initial temperature led to an increase in the combustion rate, although it was not particularly great. Thus, at 50 at. with an increase in temperature from 20 to $100\text{-}150^{\circ}$ the rate grew by 1.3 times, while at 100 at. it grew by 1.5 and 1.7 times, respectively. As regards the upper limit with respect to pressure and the anomalous character of combustion, an increase in initial temperature led to expansion of the region of stable burning.

Besides the fact that perchlorate begins to burn at lower pressures with an increase in initial temperature, the critical pressure[1] is increased. Thus, while at room temperature the critical pressure comprised 150 at., at 50° it equalled 200 at., at 100° – 250 at., and at 150° – 300 at.; the higher the temperature, the sharper is the drop in combustion rate with achievement of critical pressure. At a temperature of 175° the rate of burning could be determined only at pressures up to 100 at.; at this temperature unstable burning of another type appeared – combustion jumped up over the entire height of the specimen at excessively great rates. Apparently, at this temperature in the time of thermostatic control the specimen undergoes a significant thermal decomposition.

The graph on Fig. 2 shows the pressure dependence of the temperature coefficient of combustion rate $\beta = d \ln U/dT$ (in reciprocal degrees). This coefficient changes with a change in both the temperature range and the pressure range. In the stable burning region in the temperature interval $50\text{-}150^{\circ}$, β drops with a growth

[1]The pressure above which a drop in the burning rate sets in and combustion becomes pulsating.

in pressure up to 150 at., and then with a further increase in pressure it begins to grow sharply.[1] At 50-150 at. in the temperature range 20-50°, β grows from $2.72 \cdot 10^{-3}$ to $9.76 \cdot 10^{-3}$. From Fig. 2 it is clear that the minimum value of the coefficient β is observed at 150 at., when the combustion rate is maximum. It is known that a reduction in β with pressure has been observed also for individual explosives [8] and ballistic powders [9]. Coincidence of the minimum value of β with the maximum burning rate was noted in the works of G. V. Lukashen' for a finely dispersed mixture of ammonium perchlorate with polyformaldehyde [10].

Of the possible explanations of anomalies during combustion of ammonium perchlorate, the most probable is inhibition of combustion by water [11] which accumulates in the reaction layer of the condensed phase.[2] In this case, if the temperature on the surface of the burning perchlorate (T_s) is greater than the boiling temperature of water at the given pressure, the water will be evaporated and combustion will be stable; the reverse is also true. Thus, at an initial temperature of 20° the relationship between the temperature of the surface [3] and the boiling temperature of water at various pressures is as follows:

$$\begin{aligned} &50 \text{ at.} \quad T_{boil} = 259^\circ, \ T_s = 420^\circ, \\ &100 \text{ at.} \quad T_{boil} = 309^\circ, \ T_s = 340^\circ, \\ &150 \text{ at.} \quad T_{boil} = 360^\circ, \ T_s = 320^\circ, \end{aligned}$$

and the critical pressure, as was noted above, comprises 150 at. The displacement of the critical pressure with a growth in initial temperature toward the region of higher pressures and the expansion of the region of stable combustion which is associated

[1]It should be noted that at $p > 150$ at. the coefficient β has a somewhat formal value, since at 50° the burning of perchlorate at this pressure was of the pulsation type.

[2]The mechanism of the effect of water during combustion is apparently analogous to that proposed by Svetlov et al. [12] during thermal decay.

with it are caused apparently by the fact that the temperature of the surface of burning perchlorate grows with an increase in initial temperature, while the boiling temperature of water at the given pressure remains unchanged.

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ABSTRACT

(U) Experiments were described with ammonium perchlorate combustion at an initial temperature in the 20-150 degrees centigrade range and pressures up to 350 atm. The purpose was to explain the earlier observed anomalies of combustion characteristics and to explore the possibility of eliminating the upper explosion limit and of increasing combustion stability by increasing initial T. The burning rate U of the compacted 7 mm diameter. Samples increased, the lower explosion limit decreased, and the region of stable combustion was extended, when initial T was increased. Critical pressure also increased. Unstable combustion of a different kind appeared at initial T of 175 degrees centigrade. The minimum temperature coefficient of the burning rate coincided with the maximum U at 150 atm in the region of stable combustion. The observed anomalies were believed to be the result of combustion inhibition by water accumulated in the reaction zone. Orig. art. has: 2 figures